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DEVELOPMENT OF HELIOS TARGET INSERTION MECHANISM

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Introduction

The Los Alamos Scientific Laboratory's Helios laser fusion system focuses eight powerful CO_2 laser beams onto tiny, 200- to 300-μm-diam, DT-filled targets that are positioned near the center of a 3.5-m-diam, 3.5-m-high target vacuum (10^{-6} torr) chamber. An artist's conception of the target chamber, showing the laser beam focusing pattern, is depicted in Fig. 1. Because the target is small, a positioning system was designed to locate each target to within 5 μm of a predetermined point in space. The basic philosophy for satisfying this requirement was to (1) locate precisely a surrogate sphere, (2) align two orthogonal autocollimating telescopes to the sphere center, (3) align the laser beams to the sphere center, (4) remove the surrogate sphere, and (5) insert a target and position it so that its center coincides with the center of the cross hairs in each autocollimator. This procedure insures that the target center and each laser beam focal point are at the same space location.

Initial Alignment

A temporary fixture, called a spider, was used in the initial alignment to locate a point in space relative to the optical support structure approximately at the center of the target chamber to determine early alignment capabilities for both the autocollimators and the eight beams of the laser. This fixture was later used to locate the target insertion mechanism (TIM) after fabrication was completed. The spider was made in the shape of a cross with a centrally located pedestal (see Fig. 2). Screws were provided in the fixture for adjusting the fixture in the horizontal plane and for radial adjustment of the fixture centers. A rotatable indicator arm was mounted concentrically with respect to the pedestal. A hole precisely located in the top and on the vertical axis of the pedestal was used to mount a surrogate sphere.

The fixture was first adjusted in a laboratory to place the center of the sphere 15.2 cm above the bottom of the vertical adjusting screws; these screws are also the fixture support in the vertical direction. When the vertical adjusting screws were set on a common horizontal plane, the surrogate sphere and the pedestal were located on a common vertical axis. Then the fixture was transported to the target chamber and placed on an optical support structure ring. Using the rotating indicator arm, the sphere was positioned on the vertical axis of the optical support structure. After the sphere was positioned, the autocollimators and the eight laser beams were also aligned to the sphere center. Both the autocollimators and the laser beams were then checked for positioning capabilities. The fixture also provided

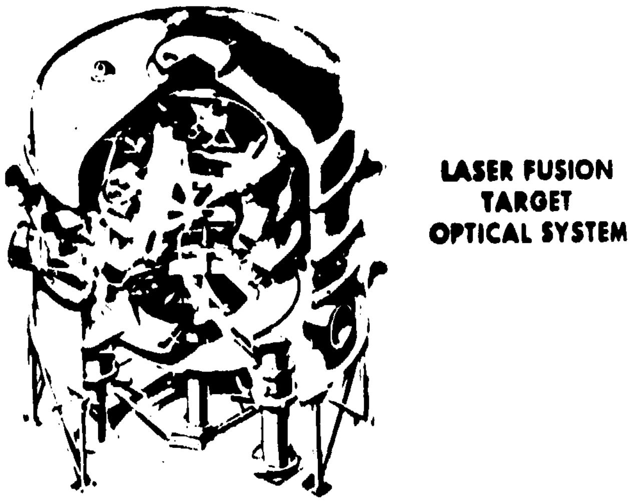


Fig. 1. Artist's conception of Helios chamber and optical support structure.

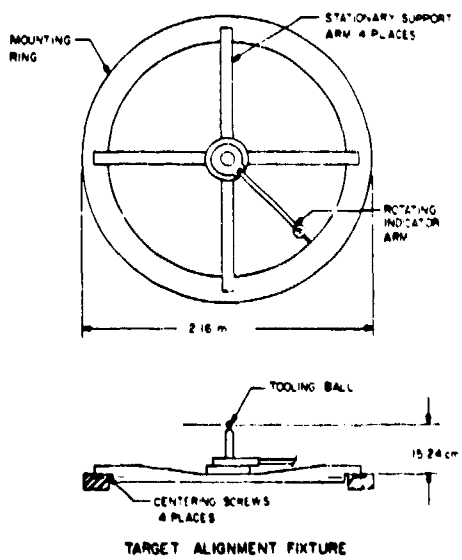


Fig. 2. Schematic representation of initial alignment fixture.

the reference point in the target chamber to which the TIM was located after completion of fabrication. The TIM and the spider fixtures coexisted in the target chamber by using the sphere in only one fixture at a time (Fig. 3). This feature was used when installing the TIM by (1) aligning the autocollimators to the sphere center when mounted in the spider, (2) removing the sphere from the spider, and (3) using the common focal point of the autocollimators as the reference for positioning the TIM so that the surrogate sphere was located to this common focal point when mounted in the TIM. After the TIM was set to this point, the surrogate sphere, as located by the TIM, became the new reference.

Target Insertion Mechanism Details

The first step in the target alignment scheme is to position a surrogate sphere with the TIM. Laser and diagnostic instrument alignment are simplified when the surrogate sphere location is repeatable to ± 2.5 μm. This necessary repeatability is achieved with a kinematic mount consisting of a hardened cone, a v-groove, and a flat, mounted on the bottom of the surrogate sphere holder mating with three hardened balls pressed into a receiver plate. The receiver plate is mounted on the end of the TIM mounting bench. Because the receiver plate and TIM mounting bench are fixed in space, the repeatability of the kinematic mount determines the repeatability of the surrogate sphere location. Figure 4 shows the cone, v-groove, and flat on the bottom of a target holder and the receiver plate containing the three balls.

The TIM is designed to insert either a target or a surrogate sphere into the target chamber through an airlock to prevent loss of vacuum. A cart, supported by four ball-bearing rollers that ride on two hardened guide rails, transports the target holder to the center of the target chamber. Cart advancement is provided by a chain-drive system powered by dc motors. Because the drive motors are located outside the target chamber and airlock, power is transmitted from the motors to the chain-drive sprockets by bellows-sealed rotary feedthroughs. Slip clutches between the motors and the feedthroughs protect against overloads that could occur if a portion of the mechanism jammed.

Fig. 3. Interior of target chamber showing initial alignment of fixture and target insertion mechanism.

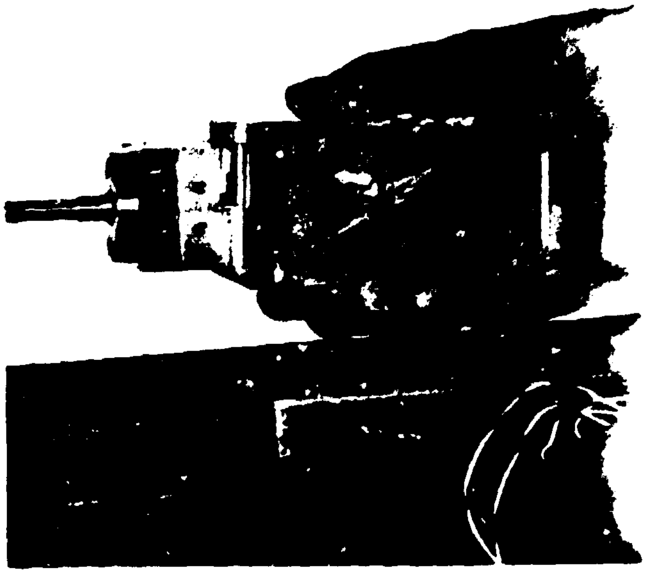


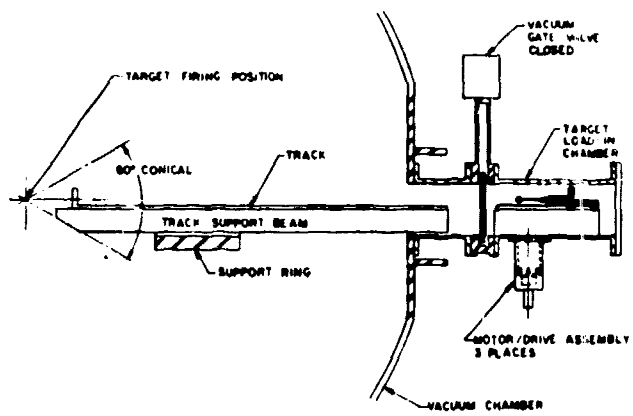
Fig. 4. Underside of target holder. The cone, v-groove, flat, and the three balls that compose the kinematic mounting are shown.

A gate valve separates the airlock from the target chamber. When the valve is open, the track inside the airlock is moved through the opening to butt against the target chamber track. The chain drive in the airlock portion of the mechanism is activated and advances the cart until it straddles both tracks. The airlock drive then releases the cart. The vacuum chamber drive attaches to the cart, moving it to the target illumination region. A schematic representation of this sequence is shown in Fig. 5.

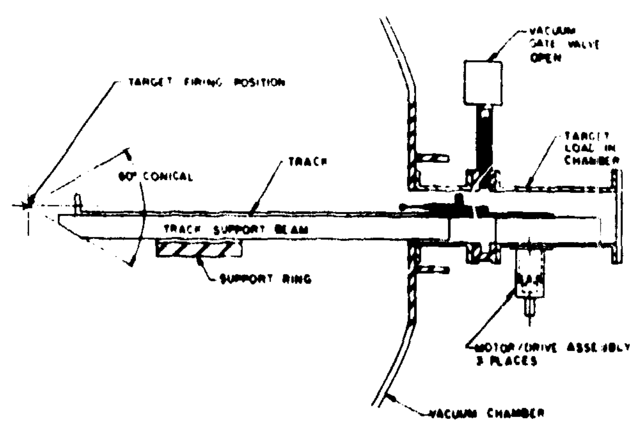
Target and surrogate sphere holders have identical kinematic mounts; therefore, the nominal target holder position can be located quite accurately. The target holder has a micropositioner for remotely moving the target ± 1 mm in the X, Y, and Z directions. Consequently, the target need only be prealigned on the target holder to ± 1 mm before insertion into the target chamber. The prealignment is very simple and quick, requiring only a plastic scale and the unaided eye.

The micropositioner is made by combining three single-axis translation stages. Each translation stage consists of a fine pitch screw (0.635-mm lead) that drives an 11.5° tapered wedge. A ball, captured in a hole, rides on the taper and pushes against a spring-loaded movable section of the translation stage. The movable section is guided by preloaded roller bearings. Figure 6 shows a cross section of a stage interior. This arrangement provides about 130 μm of motion per revolution of the lead screw.

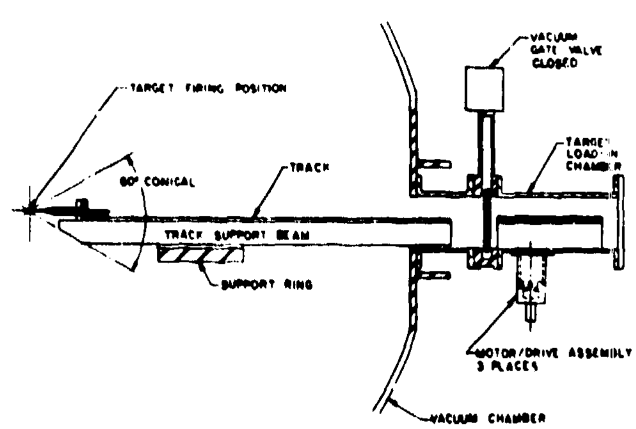
The remote drive uses three telescoping universal joints that attach to the micropositioner lead screws on one end and to friction pads on the other. The friction pads on the universal joints mate to the friction pads on the target cart. A dc motor is mounted on the cart and drives the hubs of three magnetic clutches connected in parallel. Each clutch output shaft is connected to a friction pad on the cart; thus, torque is transmitted to



(a) The target holder is loaded onto the cart anc the loading chamber pressure is reduced to that of the target chamber.



(b) The gate valve is opened and the load-in track butts against the target chamber track.



(c) The cart is advanced to the target illumination region. The load-in track is retracted. The gate valve is closed.

Fig. 5. Schematic representation of target insertion sequence.

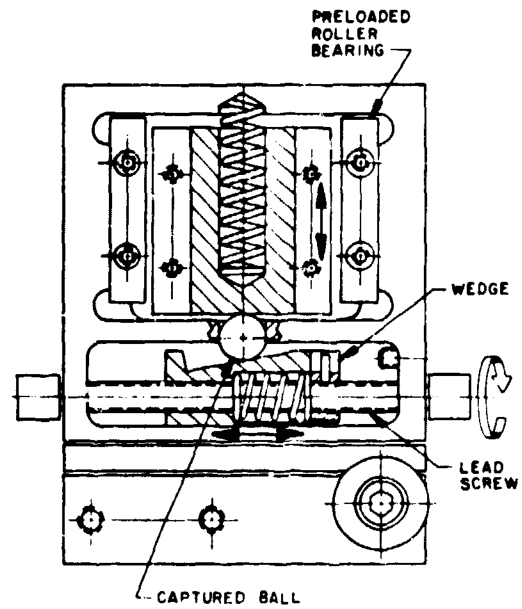


Fig. 6. Cross section of translation stage interior.

the micropositioner screws through the friction pads when the target holder pads and the cart pads are mated. A single-axis movement of the target is executed by activating the motor and a clutch for the selected micropositioner movement.

Figure 7 shows the target holder being loaded onto the cart and mating of the friction pads. Figure 8 depicts the target holder on the kinematic mount.

A T-slot was machined into the target and sphere holders to mate to a tee located on the cart. This arrangement is used to hold the target holder as the cart

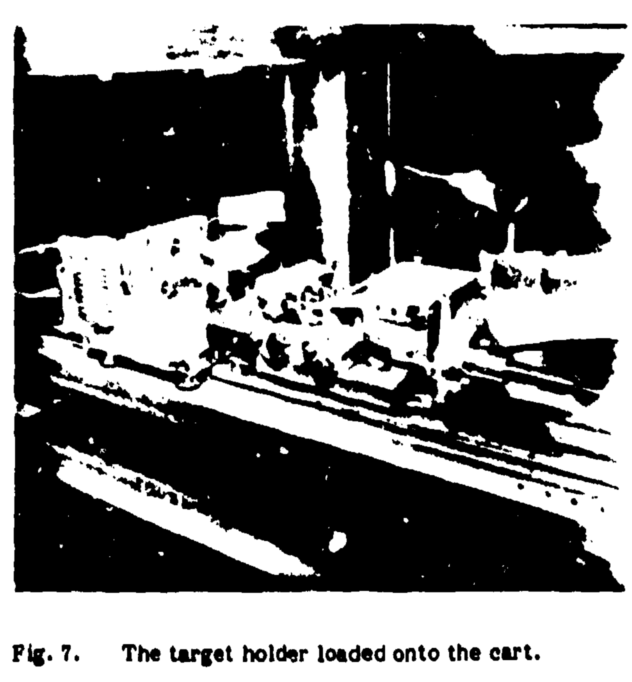


Fig. 7. The target holder loaded onto the cart.

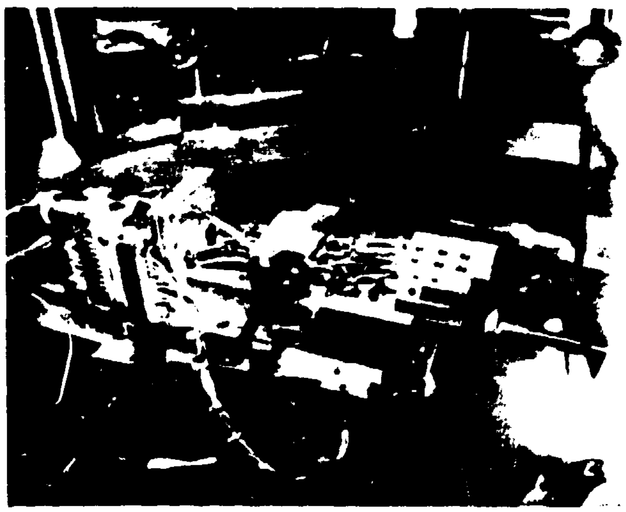


Fig. 8. The target holder on the kinematic mount.

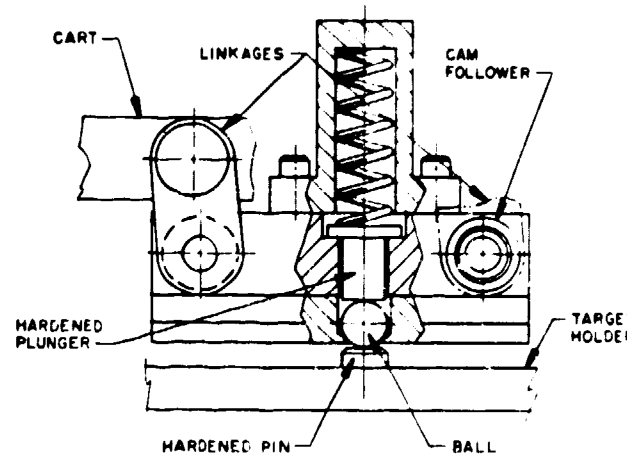


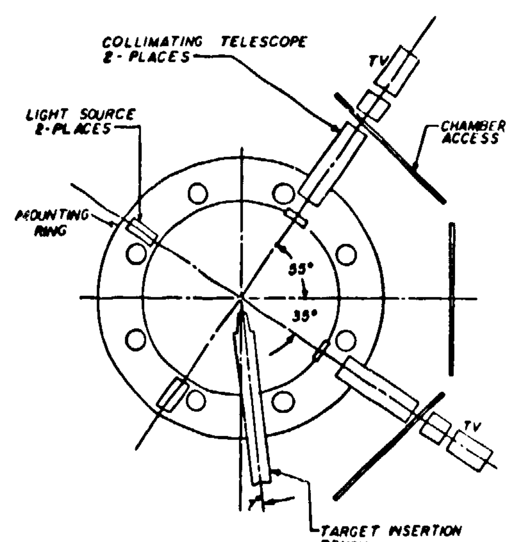
Fig. 9. Target holder loading mechanism.

is transported from the airlock to the target illumination region. The target holder can be loaded easily onto the cart and is free to move slightly as it is being located by the kinematic mount.

The tee is fastened to a plate that has two cam followers attached to the front of it. As the cart arrives at the target illumination area, the followers contact two cams that force the tee plate to be moved downward. This action permits the target holder to move above the three balls that mate into the cone, v-groove, and flat, and then to be set down until the balls and their respective mating surfaces are in contact. In Fig. 7, the tee plate carrying the target holder is shown in the "up" position. In Fig. 8, the cam follower has contacted the cam actuator, thus seating the target holder. After the target holder is seated, a vertical force must be applied to keep the holder firmly on the three balls. To assure that only a vertical force is transmitted, a ball is located between hardened flat surfaces on the plunger and target holder. Therefore, any force that is not perpendicular to the two flat surfaces will cause a rolling motion of the ball and will not affect the position of the target holder. A drawing of this loading arrangement is shown in Fig. 9.

Autocollimating Telescopes

Target positioning feedback is provided by two orthogonal autocollimating telescopes located in the target chamber as shown in Fig. 10. The target and cross-hair images are relayed to the control room by a television camera so that the operator can view the target location and position it to the cross-hair center from the control room. Figure 11 shows an aligned target as seen on the television screen. The accuracy of the target alignment depends on the ability of the optics to measure the target's position. It has been determined that with the present system the autocollimators can align to the surrogate sphere within ±3.5 μm. The target can be aligned to ±3 μm on the cross hairs. When combining these two errors, the total root-sum-square error is approximately equal to the ±5-μm permissible tolerance.



AUTOCOLLIMATING TELESCOPE PLACEMENT

Fig. 10. Location of autocollimators in target chamber.

Evaluation

After the system was designed and built, it was evaluated to determine how well it satisfied the design requirements. Three tests were performed to determine the Helios target position system effectiveness.

The first test measured the location repeatability of the surrogate sphere when placed on the kinematic mount. Two capacitance gauges and a linear variable-differential transformer were used to make this measurement. These were mounted on orthogonal axes so that the X, Y, and Z deviations could be measured simultaneously. The test results showed that the maximum deviation from the nominal position at the 99.9% confidence level, based on 90 samples, was 1.8 μm. This amount of deviation is within the allowed tolerance of ±2.5 μm.

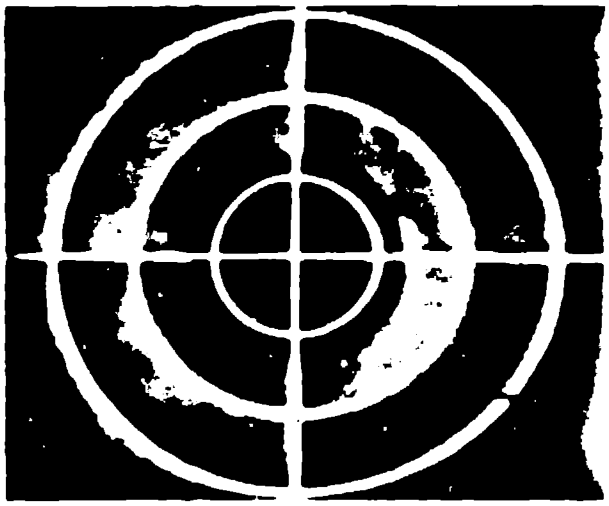


Fig. 11. An aligned target as seen on the television monitor.

It was necessary to cantilever the TIM mounting bench on the optical support structure. Therefore, a second test was conducted to measure the deflection of the target because of vibration. Measurements were made using accelerometers mounted on the target holder in the X, Y, and Z directions. The results showed that the lowest natural frequency of the TIM is about 120 Hz, and the maximum vibration amplitude at this frequency is 0.15 µm. This is quite small compared to the allowed tolerance.

The third test consisted of aligning the laser beams to the target position, as for a routine target shot, and then the laser beams were pulsed individually at low power to punch eight holes in a target. The location of the holes was measured, and the mean deviation relative to the theoretical position was 34 µm. This is an acceptable error band that represents a sum of all the possible deviations. The largest component of misalignment is attributed to error in pointing the target chamber optics.[1] This test confirmed that the target positioning error band is much less than the laser pointing error band. Figure 12 shows the theoretical and actual positions of the eight holes in the target.

The Helios target positioning system has been meeting or exceeding its design requirements for about one year with minimal maintenance. It has proven to be a very effective system.

Future Upgrades

Two major upgrades are being planned for the TIM. The first is to add the capability to change targets remotely from the control room. The second is to add the ability to process a cryogenic target.

The first upgrade will be performed in two steps. The initial step will consist of mounting the alignment sphere holder in the target chamber so it can be placed on the kinematic mount without going through the airlock. This allows laser and autocollimator alignments to be performed while the next target is being loaded onto the cart. This should reduce the target changing time to about half the time now required. (It now takes about 30 minutes to go through the alignment and target-changing sequence.) The subsequent step will be to place a turret into the airlock that contains many targets. A mechanism will be developed to unload a spent target remotely, index the turret, and load a new target from the control room. This second step will further reduce the time and manpower needed to accomplish the alignment and target-changing tasks. The mechanism for processing and positioning a cryogenic target is being developed and will be incorporated into the Helios system sometime in the next two years.

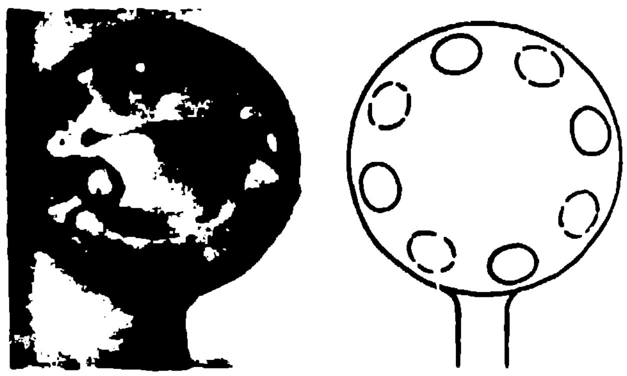


Fig. 12. Position of laser-induced holes on a target.

Acknowledgments

The design, fabrication, and installation of the target insertion mechanism were the result of many dedicated people. The authors particularly acknowledge the efforts of E. H. Farnum, B. M. Fox, J. A. Hanlon, W. G. Hansen, E. E. Langley, G. E. McCarty, J. R. Miller, H. F. Muffly, B. L. Norris, D. W. Parker, L. D. Sanders, and R. W. Teasdale.

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